



Effort to Accelerate MBSE Adoption and Usage at JSC

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**AIAA Space 2016, September 15, 2016
Long Beach California**



Agenda



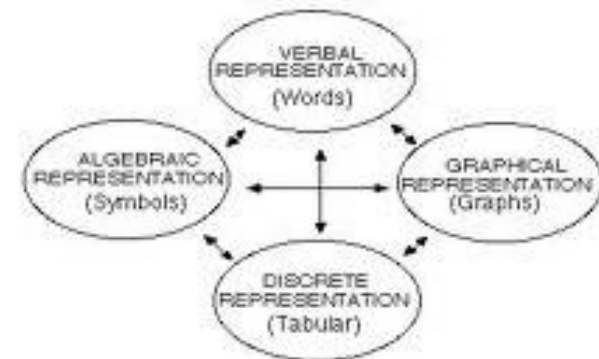
- ◆ **Motivation**
- ◆ **Challenges to MBSE Adoption**
- ◆ **Effort to Facilitate MBSE Adoption**
 - Approaches to Address Challenges
 - Modeling Methods
 - Reusable Model Elements
 - Toolset
 - Project Case Studies
- ◆ **Conclusion**



Motivation Catalyst



- ◆ **Spacecraft design and operation stakeholders are creating models/artifacts of the same system with different processes, tools, and representations.**
- ◆ **These oft uncoordinated approaches create locally successful products but also create a communication barrier among the various stakeholders (the “Tower of Babel” Effect).**
- ◆ **The same information is captured multiple times, in multiple places, with multiple representations, creating a maintenance challenge.**





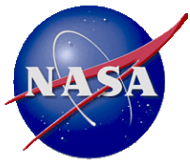
MBSE at JSC



- ◆ JSC has applied MBSE using SysML to a number of advanced projects since 2009
- ◆ Objective of MBSE is to reduce product cycle time, improve product quality, and product maintainability
- ◆ MBSE provides a formal understanding of the features and structure of a product



Challenges to MBSE Adoption



1. Force of inertia impedes MBSE Adoption

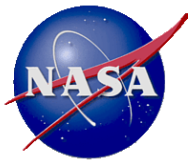
- High risk environment (space projects) tends to gravitate toward conservative engineering
- Over valuation of current approaches to achieve success
- Perception that potential long term benefits are outweighed by short term risks
- Stories, real or perceived, of undelivered promises of MBSE are often presented to challenge the move

2. Additional Costs & Efforts Associated with MBSE Adoption

- Adopting MBSE requires additional costs
 - Buying enough tool licenses & trainings
- Additional effort to build the models
 - Learning a tool
 - Time consuming effort to build the model from scratch
 - Starting the model development can be daunting
 - Limited readily available library of reusable system models
 - Extra costs associated with early adoption for small and short duration projects



Challenges to MBSE Adoption

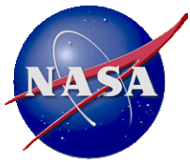


3. Difficulty in getting started with MBSE

- No roadmap to follow the best practices required for successful adoption
- Multiple issues need to be resolved even at the start of a project
 - What training is needed for whom?
 - What is the right mix of team skills needed?
 - What modeling methodology to use?
 - What tool to use?
 - Are there some guidelines or a process to follow?
- SysML language semantic is very rich and complex
 - Difficult to decide which modeling technique is appropriate for the project
 - After classroom training sessions, modelers still do not know how to begin
 - No defined process to guide modelers in the development of the SysML model representing the target system
- MBSE is first and foremost Systems Engineering
- NASA Systems Engineering Handbook does not provide much guidance regarding MBSE



Approaches to offset “force of inertia”



- ◆ **Alleviate the perception of increased risks using targeted presentations focused on**
 - Benefits of using MBSE
 - Availability of the models tools
 - Successful project experiences
 - Emphasize the value proposition
 - Provide evidence on how the project can benefit by adopting MBSE
- ◆ **Identify a project champion**
 - JSC SysML User's Group help champion the change
 - Systems Engineers are the primary target audience.
- ◆ **Provide tools and concrete added value examples that benefit SME daily activities**
 - ◆ SME does not have direct responsibility for system engineering
- ◆ **Demonstrate the capability to support communication between all the project stakeholders**



Approaches to address “Additional Costs and Efforts” for MBSE Adoption



- ◆ **Requires a combination of institutional and project support for training software tool licenses**
- ◆ **Provide for a team of expert modelers that can be matrixed into the project for successful MBSE adoption**
 - Experienced Modeler is partner with the System Engineers to support adoption of modeling practices and tools
 - Project Mentor is part of the project team and be involved in the system integration and design

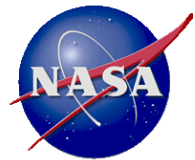


Approaches to address “how to get started?”



- ◆ **“Model with a Purpose” is an important concept for successful adoption**
 - Helps clearly define the goal and objective of the project
 - Helps manage expectation with the stakeholders
 - Helps narrowing down modeling methods
 - Helps identify the most appropriate modeling diagrams

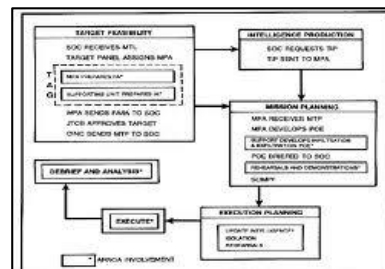
- ◆ **JSC System Modeling Team (JSMT) focused on**
 - Developing modeling methods
 - Developing tools to generate project artifacts
 - Providing modeling and tool guidelines
 - Providing exemplary reference models
 - Providing reusable model component



Artifacts by Multiple Stakeholders



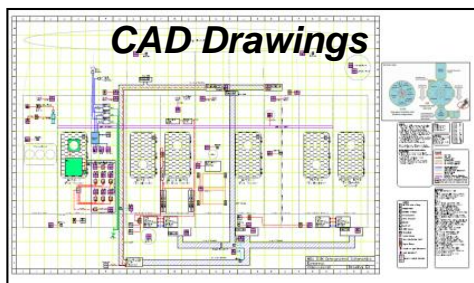
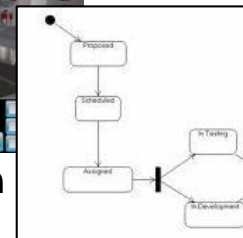
Telemetry and Command



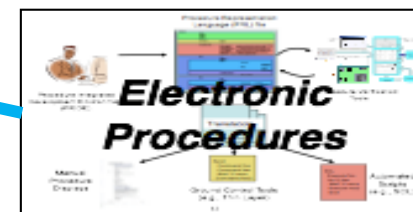
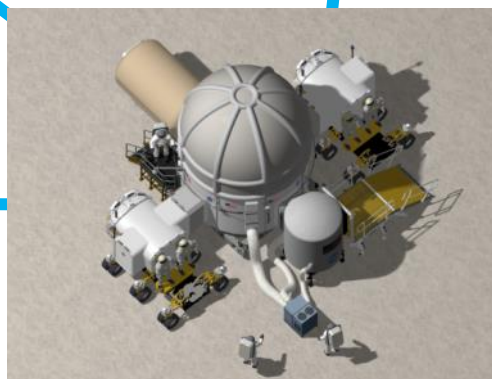
Mission Operation Planning



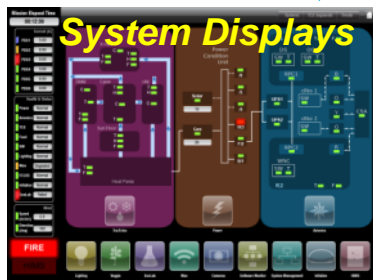
Simulation



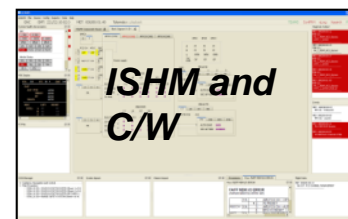
CAD Drawings



Electronic Procedures



System Displays

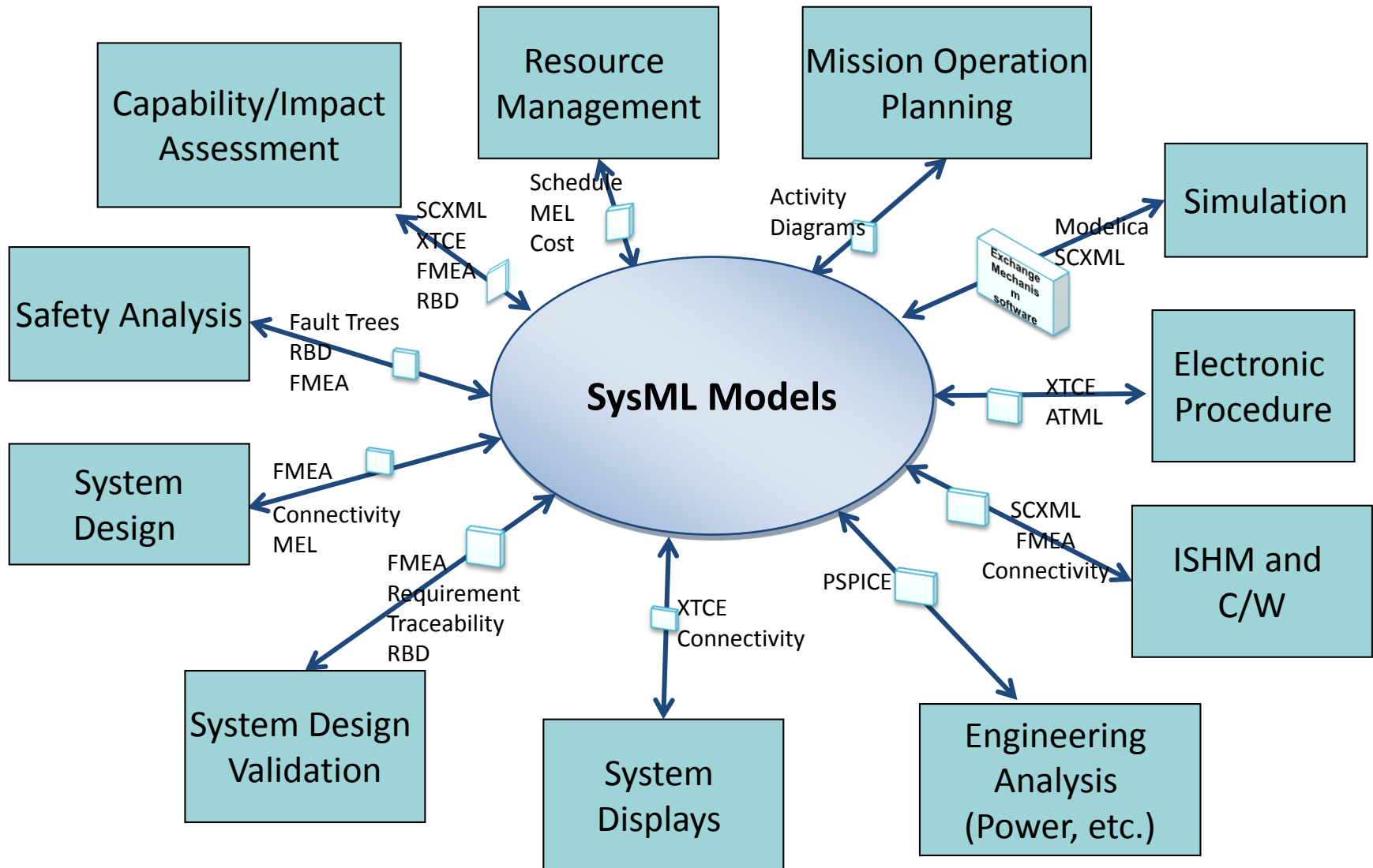


ISHM and C/W



Uses of System Models

Model once and Use many times





Experience with SysML Modeling and Tool Set Development



- ◆ **Developed a modeling methodology**
- ◆ **Developed SysML Models for Multiple NASA Projects:**
 - *Deep Space Habitat (DSH)/ Habitat Demonstration Unit (HDU)*
 - *Exploration Augmentation Module (EAM)*
 - *Integrated Power and Avionics System (IPAS)*
 - *Cascade Distiller System (CDS) Life Support System (LSS)*
 - *Human Exploration Testbed Integration and Analysis (HESTIA)*
 - *Advanced Exploration System - Modular Power Systems (AMPS)*
 - *Orion*
- ◆ **Developed SysML Library Repository**
 - *Collection of SysML Models*
- ◆ **Provide a suite of data exchange tools**
 - *To extract System Engineering products from the models*
 - *To build models by extracting automatically or semi automatically information from existing sources*
 - *To support Fault Management engineering*

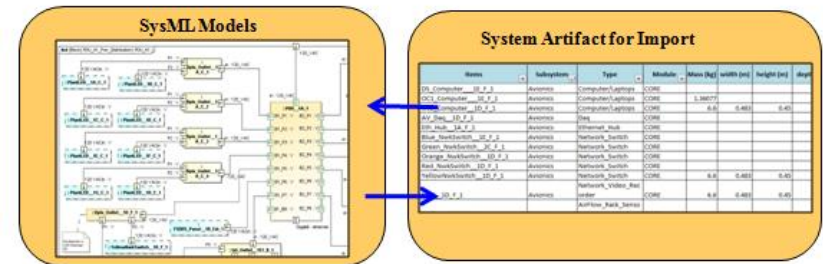


Model Based Engineering/ SysML Data Exchange Tool Development



- Plug-Ins in use by NASA projects:

1. **MEL plug-in:** Generates a Master Equipment List (MEL); mines data related to SysML block attributes and relationships
2. **Connectivity plug-in:** Generates connectivity and conveyed information data
3. **FSM plug-in:** Generates Finite State Machine data for use by simulator engines
4. **XTCE plug-in:** Generates Command and Telemetry data (via XML file)
5. **SysML Builder plug-in:** Generates SysML elements and diagrams from an Excel/CSV template (for SysML modelers and AutoCAD data extraction)
6. **FMECA plug-in:** Generates a subset of FMECA data (failure modes and derives end effects)
7. **FTA plug-in:** Generates Fault Tree Analysis for a selected event



- ◆ **Prototype Plug-Ins:**

8. **PRA plug-in:** Traverses the behavior diagrams extracting the reliability values and compute the system reliability numbers.
9. **UUT plug-in:** Generates ATML (Automated Test Mark-Up Language) for Unit Under Test (UUT)
10. **Power Analysis plug-in:** Traverses connectivity to calculate total current
11. **PSpice Netlist plug-in:** Generates P-SPICE netlist from SysML models
12. **GUNNS/Trick plug-ins:** Generates data for the General-Use Nodal Network Solver (GUNNS) modeling software for use with NASA's Trick simulation environment
13. **TEAMs plug-in:** Generates Failure Mode and connectivity data for import to TEAMs tool
14. **Parametric Analyzer Plug-in:** Runs parametric analysis



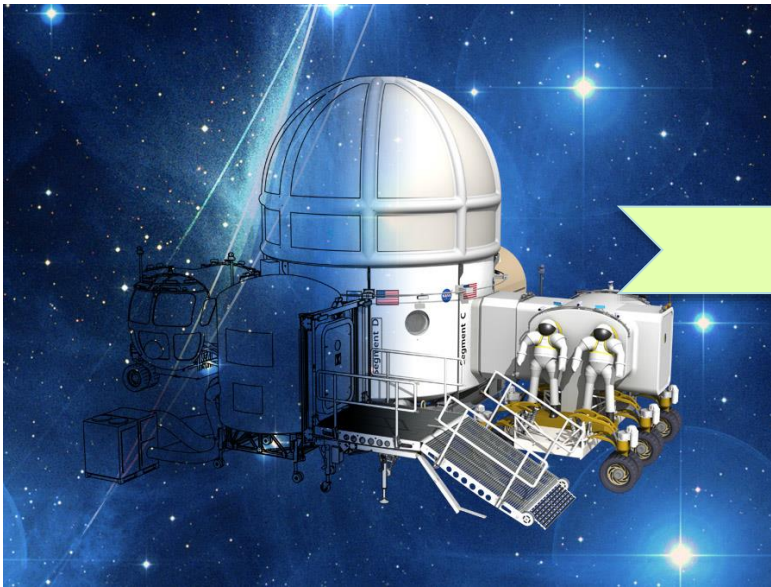
Case Study 1 – HDU/DSH



◆ Multi-center Technology Investment Project started in 2010.

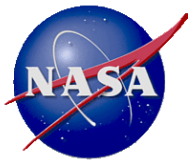
◆ Objectives:

- Evaluate and validate Lunar Surface System (LSS) Habitat Concept efficiency and effectiveness
- Build, integrate, test, and evaluate the vertical habitat configuration utilizing developmental hardware & software





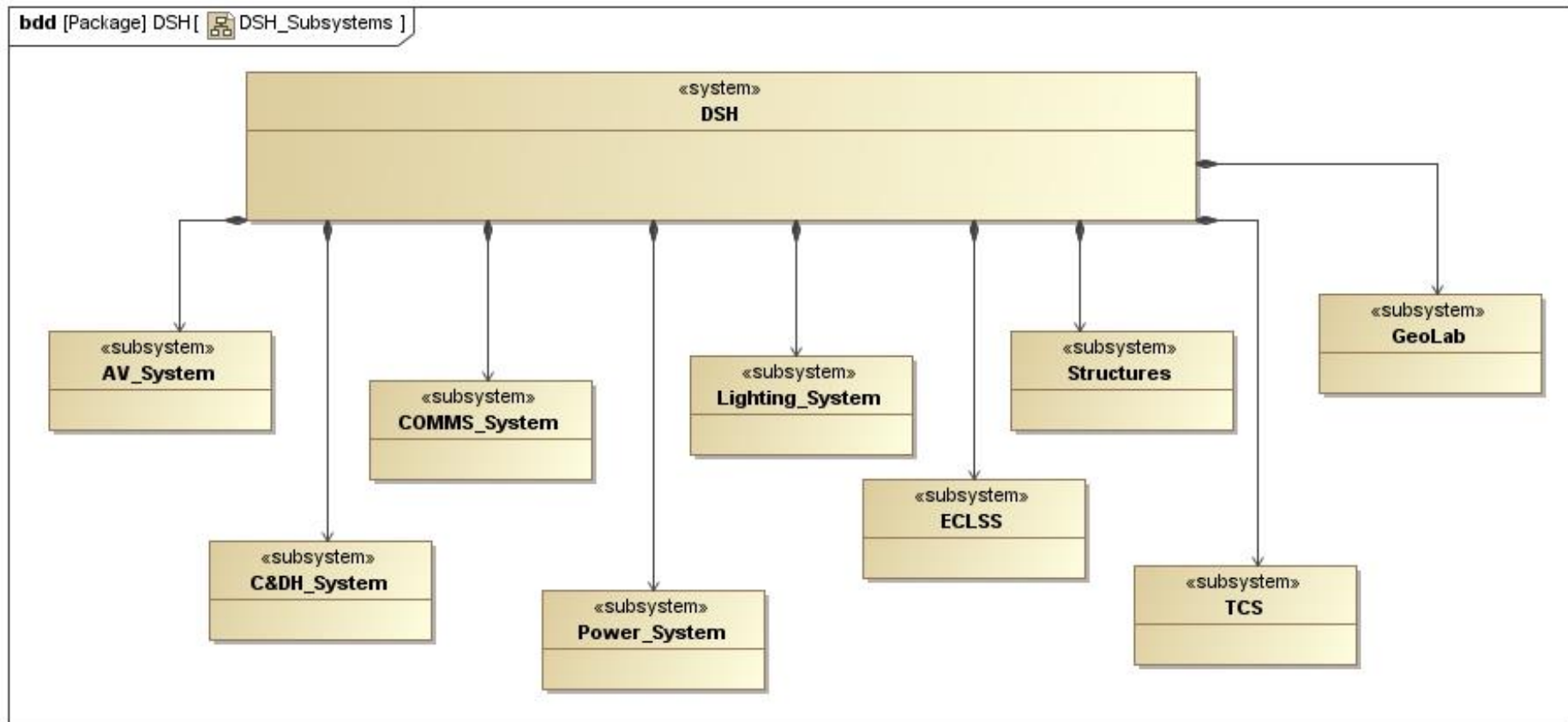
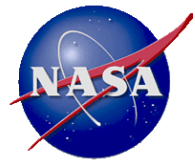
HDU/DSH Modeling and Tool Overview



- ◆ The team's role in support of the HDU/DSH project was developing the software architecture
 - Maintaining command and telemetry dictionaries, creating crew displays, developing electronic procedures
- ◆ An initial modeling approach was developed specifically targeted to the products needed for the hardware/software integration
 - The initial target artifacts were system connectivity representation to populate crew displays and XTCE to capture Telemetry and Commands for various software applications
- ◆ Detailed SysML models of all the subsystems including a full set of structural and behavioral models were built throughout the design phase
- ◆ The model and SysML tools were used to support HDU/DSH surface operations and testing.

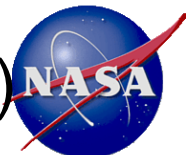


DSH System Model

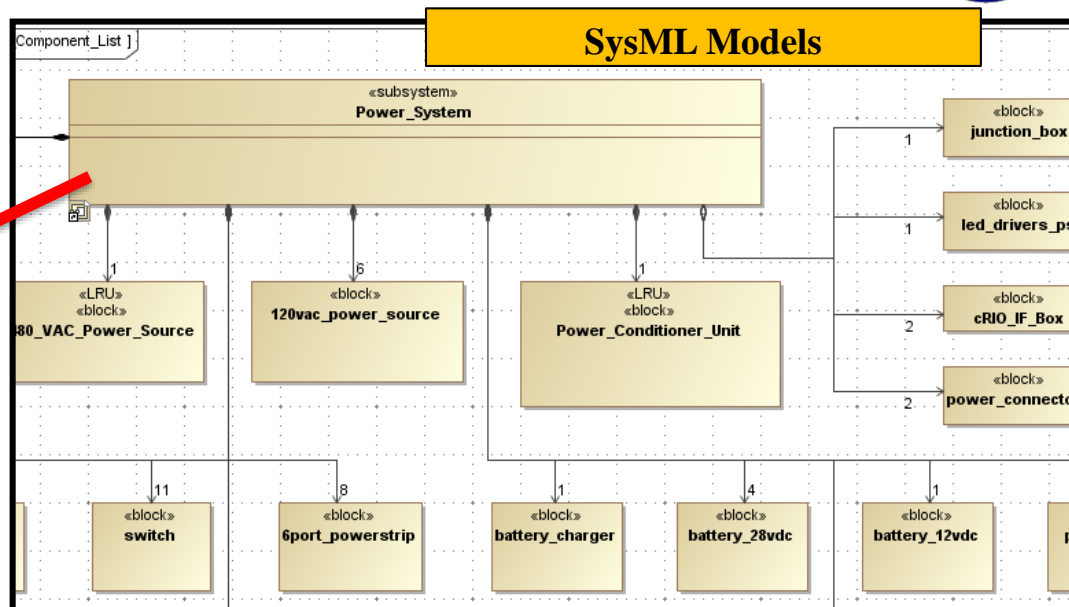




Created tool to generate master equipment list (MEL)



Magic Draw Plug-Ins



MEL

	A	B	C	D	G	H	I	J	K	L	M	N
	Component Type (* = Removed Items or Test Articles)	Subsystem	Documentation	Qty	Mass (kg)	width (m)	height (m)	depth (m)	Avg Power (W)	Max Power (W)	Voltage Type	No
1	pdu	Power_System		6		0.114	0.4449986	0.089				
2	dplx_outlet	Power_System		47								
3	quad_outlet	Power_System		12								
4	battery_12vdc	Power_System		1		0.181	0.167	0.076				
5	battery_28vdc	Power_System		4								
6	battery_charger	Power_System		1					80		120VAC	
7	poe_injector	Power_System		1								
8	6port_powerstrip	Power_System		8	1.36				60			
9	rpc	Power_System	Avionics Power Distribution Unit aka RPC	2	4.5	0.445	0.089	0.114	1	1	120 VAC	
10	ups_accumetrics	Power_System	Uninterrupted Power Supply (Accumetrics)	2	19.73	0.09	0.043	0.041	140	140	120 VAC	
11	120vac_to_12vdc_converter	Power_System		2								
12	120vac_to_24vdc_converter	Power_System		3								
13	variable_converter	Power_System		1	8.6	0.254	0.2032	0.1016				

Created tool to extract connectivity

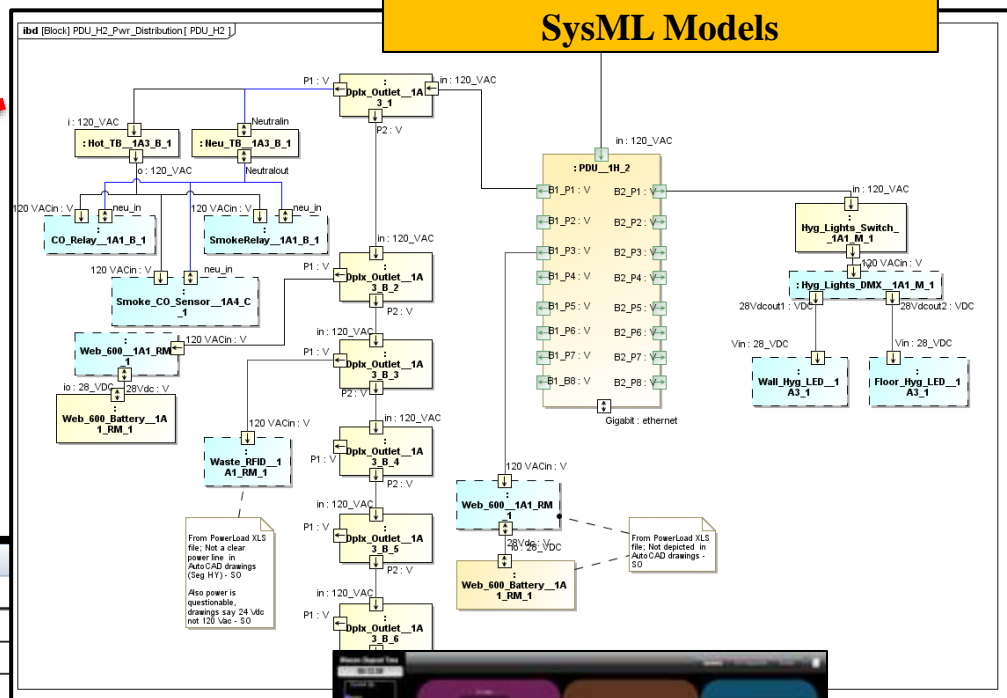
Magic Draw Plug-Ins



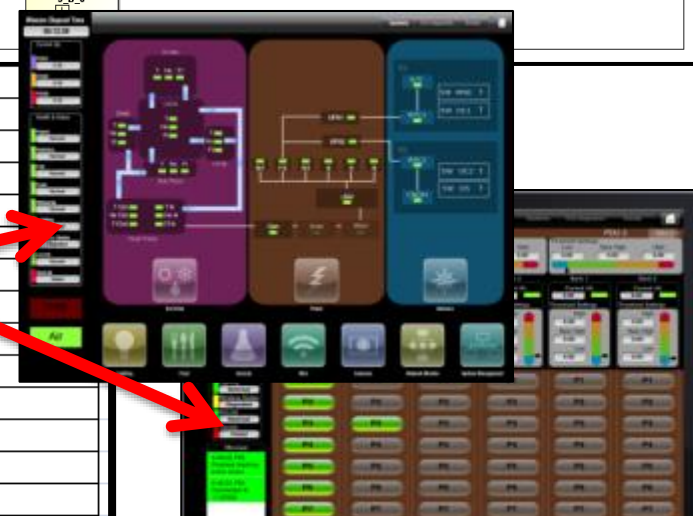
Connectivity

source	destination	source port	target port	type
PDU_1H_1	Hot_TB_1H_B_1	B2_P3		
PDU_1A_1	Dplx_Outlet_1E2_M_1	B2_P7		
Hot_TB_1E2_1	O2Sensor_1E2_RT_1	o		
PDU_1B_2	Dplx_Outlet_1B_B_2	B1_P4	in	Power
Green_NwkSwitch_2C_F_1	Cam_VS_2C_F_1	P7	Gigabit	Data
Green_NwkSwitch_2C_F_1	Laptop_2_1	P13		1 Data
Spotlight_Switch_1A_M_2	Spotlight_1D_Ext_1		28Vdcin	Power
PDU_1A_1	Dplx_Outlet_1F_B_1	B2_P2	in	Power
Dplx_Outlet_1A3_B_5	Dplx_Outlet_1A3_B_6	P2	in	Power
Blue_NwkSwitch_1E_F_1	GB_Eth_Hub_1H_1	P14		1 Data
Hot_TB_1E2_1	CO_Relay_1E2_RM_1	o	120 VACin	Power
Dplx_Outlet_1A_C_1	PlantLED_1B_C_1	P2	120 VACin	Power
Pwr_Connector_1D_F_1	RPC_1D_F_1		1in	Power
Pwr_Connector_1D_F_1	RPC_1D_F_1		2in	Power
Signal_TB	SmokeRelay_1H_F_1	smoke		Data
Dplx_Outlet_1F_F_2	28_VDC_PS_1F_F_1	P1		Power
PDU_1A_1	Dplx_Outlet_1B_B_1	B2_P3	in	Power
Hot_TB_1H_B_1	Smoke_CO_Sensor_1D_T_1	o	120 VACin	Power
28_VDC_PS_1F_F_1	28_VDC_TB_1F_F_1	o	in	Power

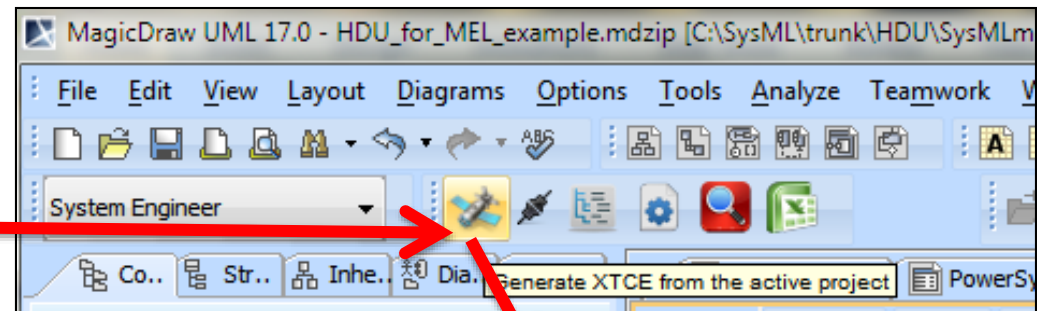
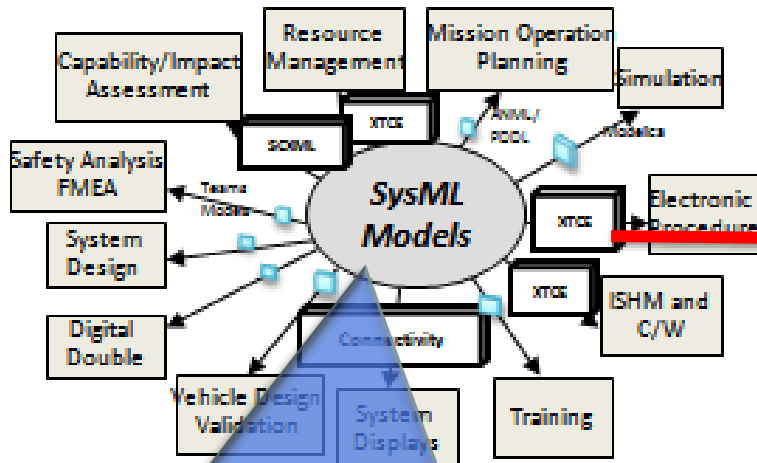
SysML Models



Utilized in Connectivity Applications

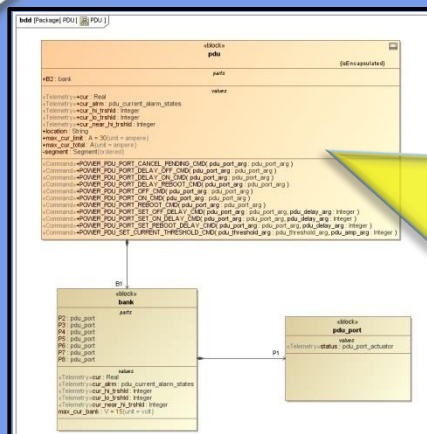


Created tool to extract XTCE



XML Telemetric and Command Exchange (XTCE) : OMG standard for Spacecraft T&C

```
<SpaceSystem name="RIU2">
  <AliasSet>
    <Alias alias="02" nameSpace="id"/>
    <Alias alias="020602" nameSpace="interface"/>
  </AliasSet>
  <Header classification="INTERFACE"/>
  <TelemetryMetaData>
    <ParameterSet>
      <Parameter parameterTypeRef="HUMIDITY_DEWPOINT_SENSOR"
shortDescription="GEOLAB_GB_HUMIDITY1_DEWPOINT_SENSOR"
name="020602018001">
        <ParameterProperties dataSource="telemetry">
        </ParameterProperties>
      </Parameter>
      <Parameter parameterTypeRef="VALIDITY" name="020602054001">
        <ParameterProperties dataSource="telemetry">
        </ParameterProperties>
      </Parameter>
      <Parameter parameterTypeRef="HUMIDITY_PRESSURE_SENSOR"
name="020602018001">
        <ParameterProperties dataSource="telemetry">
        </ParameterProperties>
      </Parameter>
    </ParameterSet>
  </TelemetryMetaData>
  <CommandSet>
    <Command name="POWER_PDU_PORT_CANCEL_PE"
shortDescription="POWER_PDU_PORT_CANCEL_PE"
name="020602018001">
      <CommandProperties dataSource="telemetry">
      </CommandProperties>
    </Command>
    <Command name="POWER_PDU_PORT_DELAY_OFF"
shortDescription="POWER_PDU_PORT_DELAY_OFF"
name="020602018001">
      <CommandProperties dataSource="telemetry">
      </CommandProperties>
    </Command>
    <Command name="POWER_PDU_PORT_DELAY_ON"
shortDescription="POWER_PDU_PORT_DELAY_ON"
name="020602018001">
      <CommandProperties dataSource="telemetry">
      </CommandProperties>
    </Command>
    <Command name="POWER_PDU_PORT_DELAY_REB"
shortDescription="POWER_PDU_PORT_DELAY_REB"
name="020602018001">
      <CommandProperties dataSource="telemetry">
      </CommandProperties>
    </Command>
    <Command name="POWER_PDU_PORT_OFF_CMD"
shortDescription="POWER_PDU_PORT_OFF_CMD"
name="020602018001">
      <CommandProperties dataSource="telemetry">
      </CommandProperties>
    </Command>
    <Command name="POWER_PDU_PORT_ON_CMD"
shortDescription="POWER_PDU_PORT_ON_CMD"
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      <CommandProperties dataSource="telemetry">
      </CommandProperties>
    </Command>
  </CommandSet>
</SpaceSystem>
```

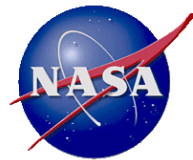


```
<Telemetry>+cur : Real
<Telemetry>+cur_alarm : pdu_current_alarm_sta
<Telemetry>+cur_hi_trshld : Integer
<Telemetry>+cur_lo_trshld : Integer
<Telemetry>+cur_near_hi_trshld : Integer
+location : String
+max_cur_limit : A = 30{unit = ampere}
+max_cur_total : A{unit = ampere}
-segment : Segment{ordered}

<Command>+POWER_PDU_PORT_CANCEL_PE
<Command>+POWER_PDU_PORT_DELAY_OFF
<Command>+POWER_PDU_PORT_DELAY_ON
<Command>+POWER_PDU_PORT_DELAY_REB
<Command>+POWER_PDU_PORT_OFF_CMD
<Command>+POWER_PDU_PORT_ON_CMD
```



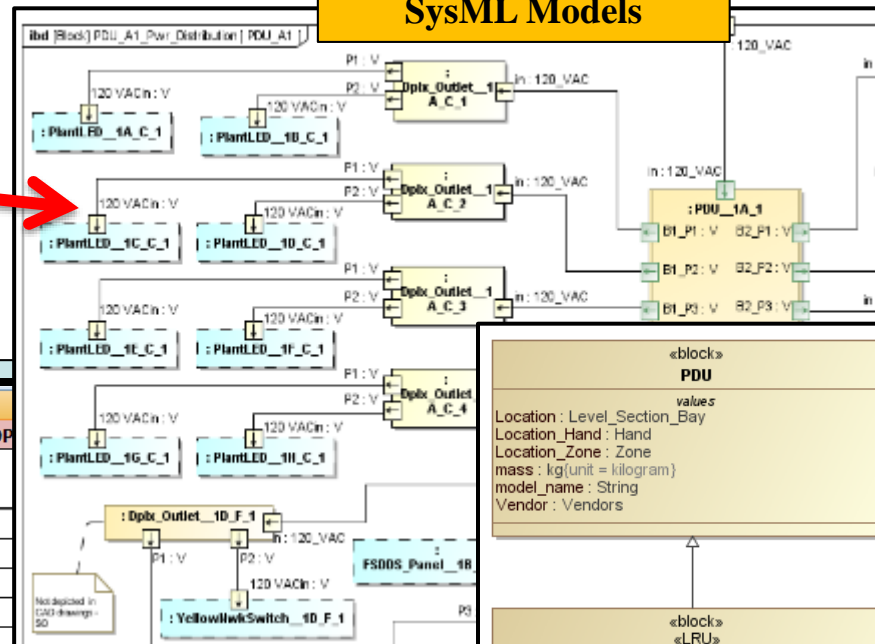
Created a tool to import data and generate SysML models



Magic Draw Plug-Ins



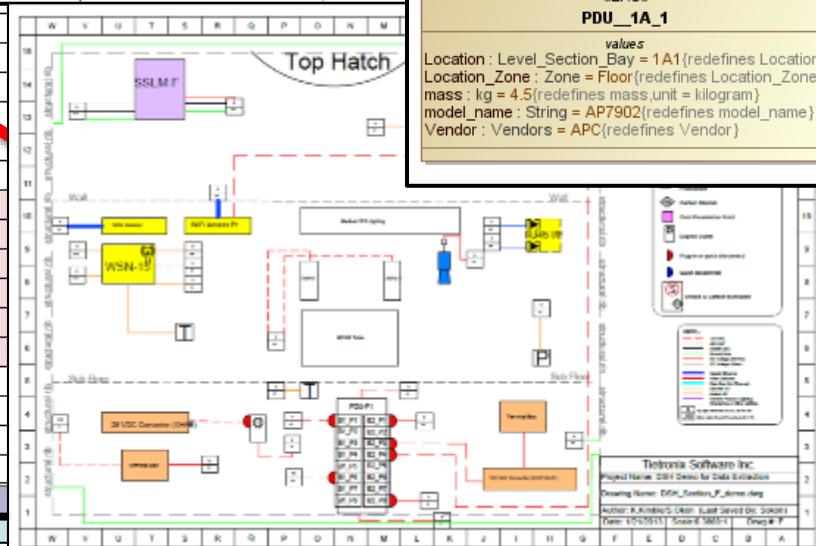
SysML Models



Artifacts for Import

	A	B	C	D	E	
1	BLOCK					PROP
2	BLOCK	BASE	BLOCK EXTENSION	PROPERTY	NAME	
4	Avionics		Subsystem			
5	Power_System		Subsystem			
6	PCU					
7	pdu_with_port_test					
8	port_test					
9	B1_P1	port_test				
10	B1_P2	port_test				
11	B1_P3	port_test				
12	B2_P1	port_test				
13	B2_P2	port_test				
14	B2_P3	port_test				
15	pdu_with_port_test	port_test		Part	B1_P1	
16	pdu_with_port_test	port_test		Part	B1_P2	
17	pdu_with_port_test	port_test		Part	B1_P3	
18	pdu_with_port_test	port_test		Part	B2_P1	
19	pdu_with_port_test	port_test		Part	B2_P2	
20	pdu_with_port_test	port_test		Part	B2_P3	
21	tb					
22	Converter					
23	cRIO_test					
24	computer_test					
25	Power_Conditioner_Unit_1x	PCU				

AutoCAD to CSV Generation



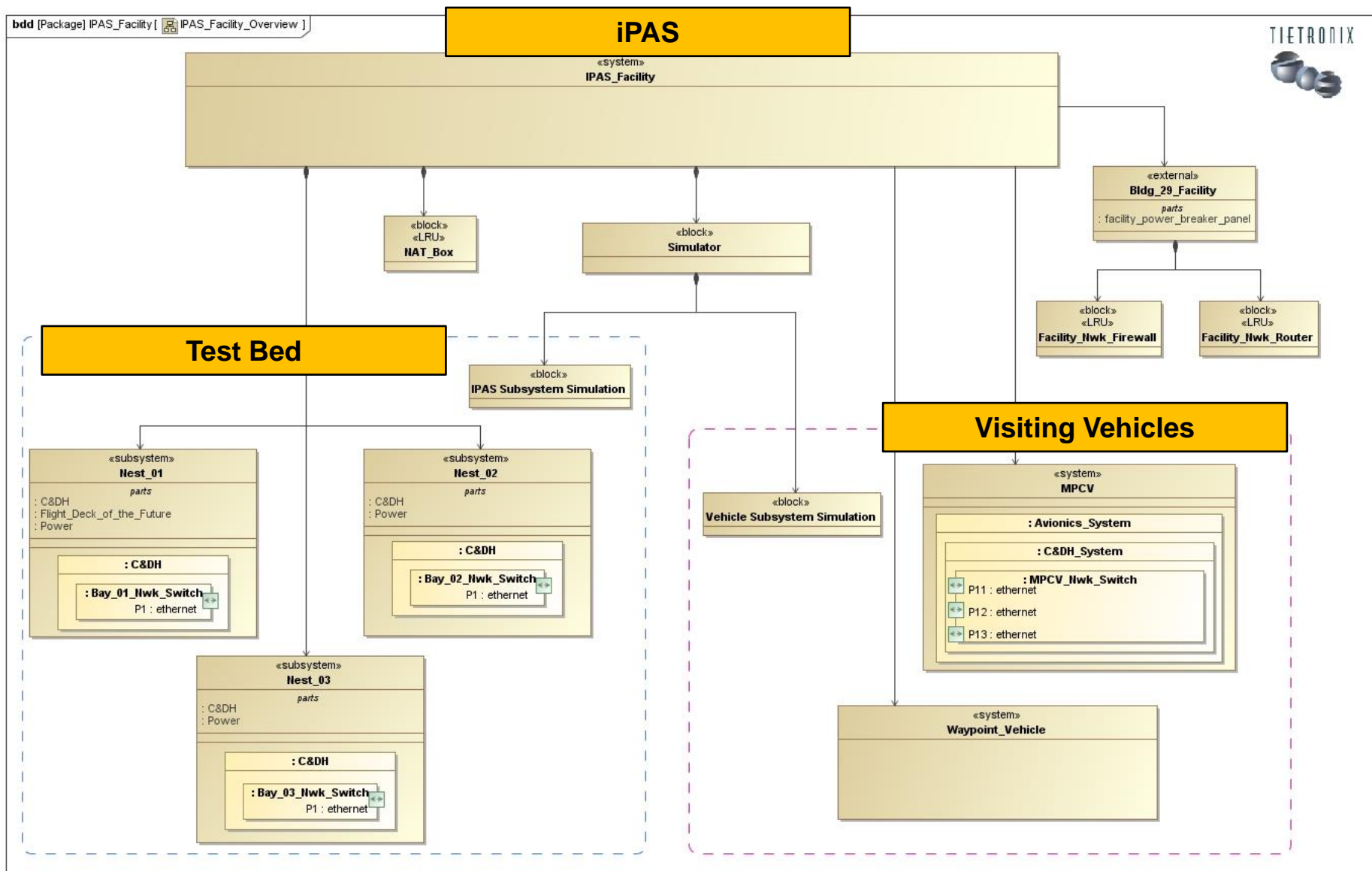


Case Study 2 - Integrated Power, Avionics and Software (iPAS)

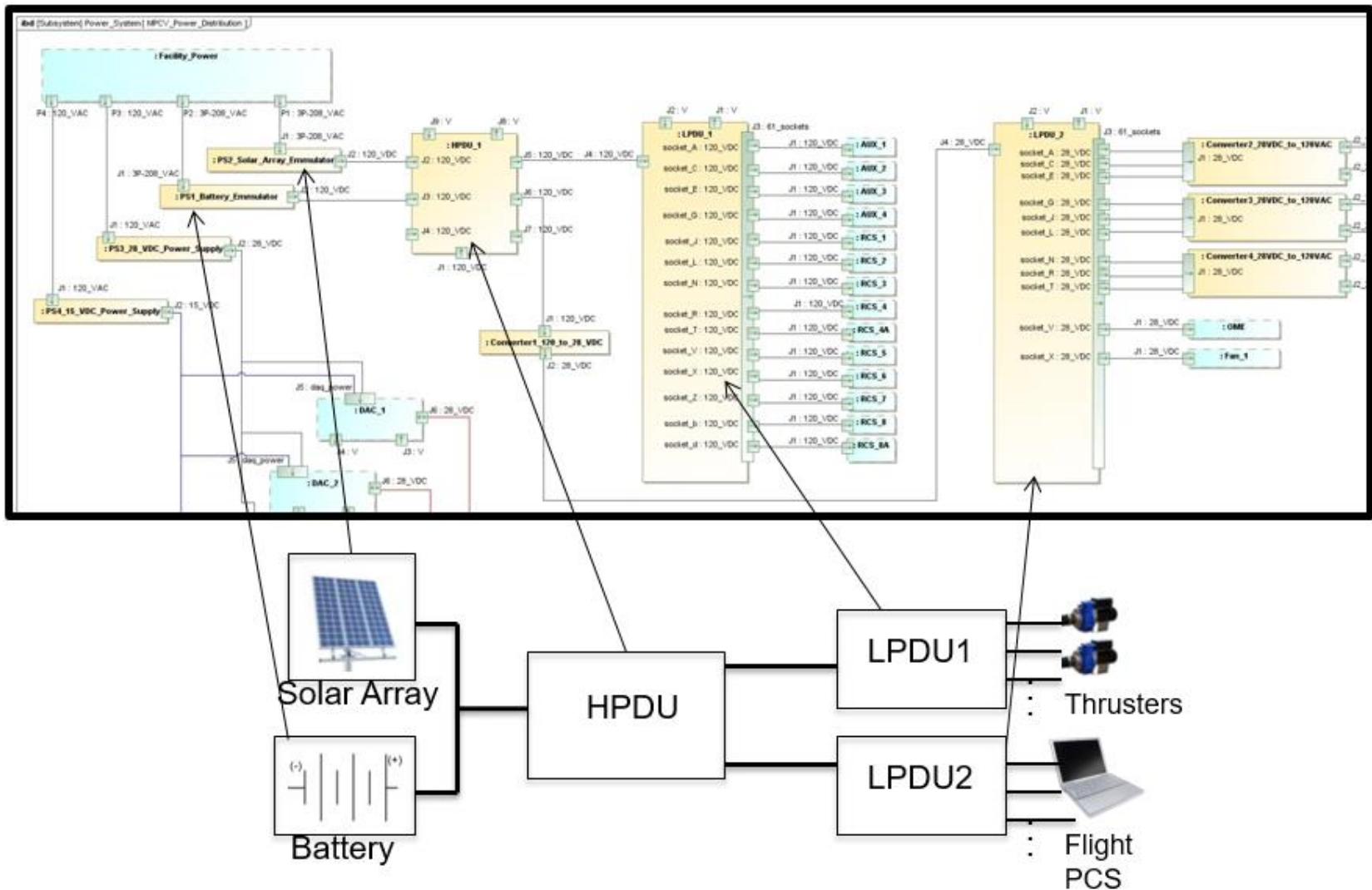


- ◆ iPAS is a testing facility focusing on the integration of visiting vehicles to test new technologies
- ◆ The import tool, built for the previous HDU project, was used to build the iPAS SysML models
 - Model included Power, Avionics, Command & Data Handling, and Propulsion systems
 - The iPAS model captured system architecture, connectivity and command and telemetry attributes
- ◆ The project used the tools to extract master equipment list, connectivity, and XTCE information from the model.
- ◆ Using the tools and established modeling method, the model development and data extraction was completed in a week.

iPAS Facility (Avionics Focus)

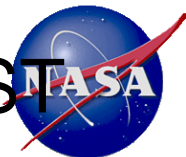


iPAS Power Distribution Model for MPCV

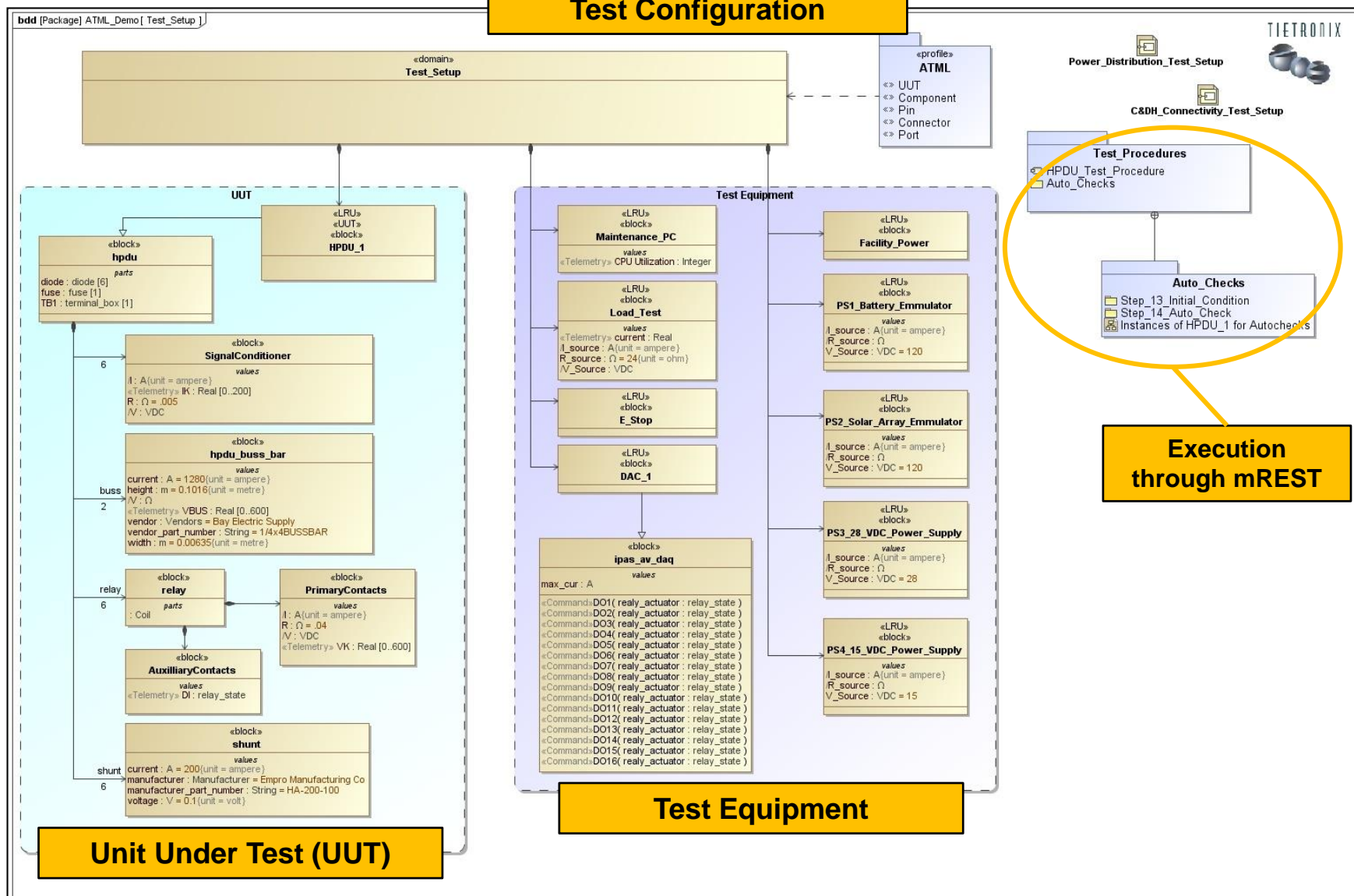




iPAS – Model Design for ATML and mREST



Test Configuration

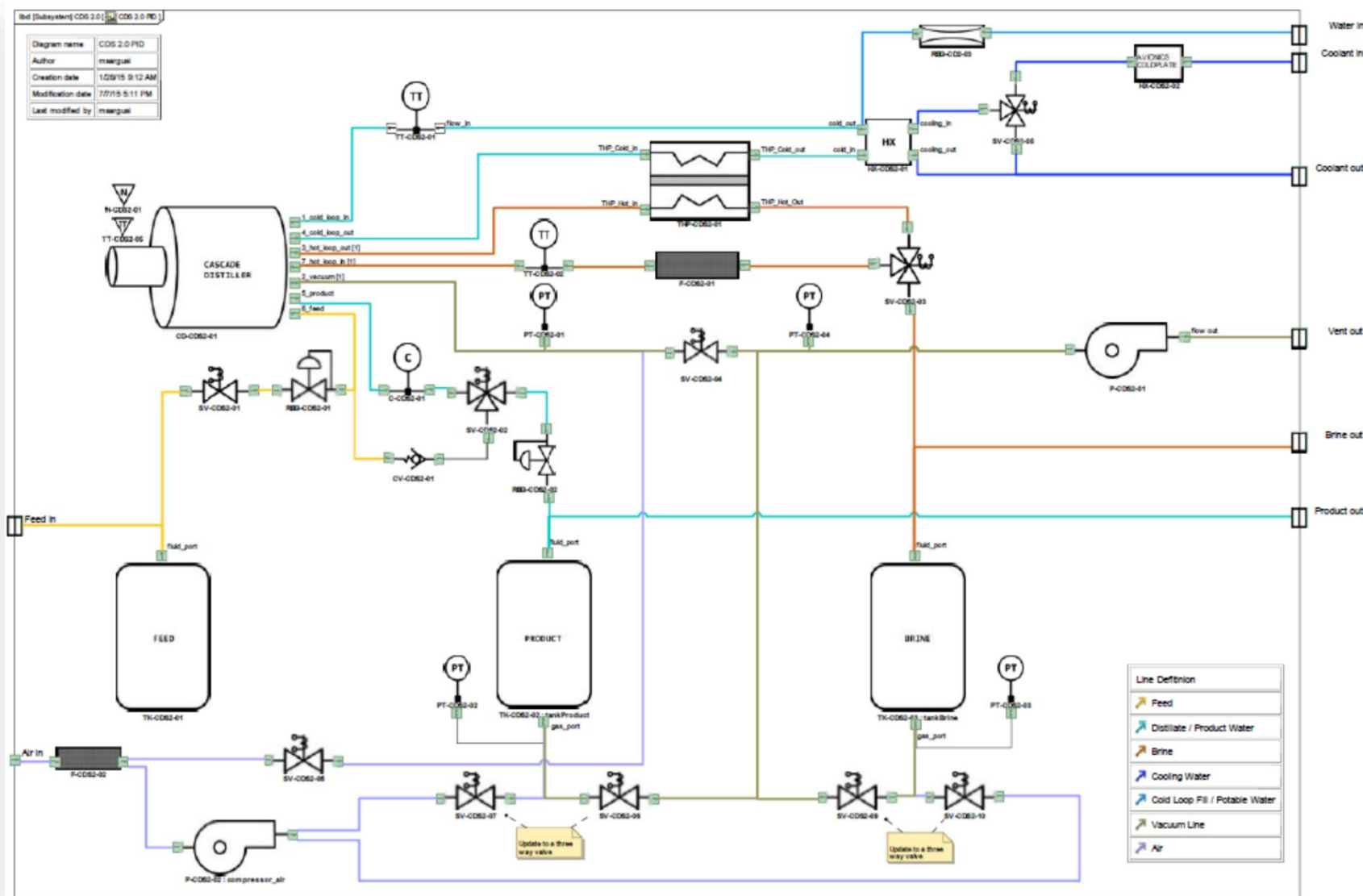


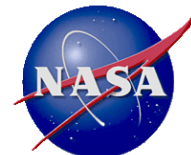


Case Study 3 – Cascade Distillation System (CDS) Life Support System

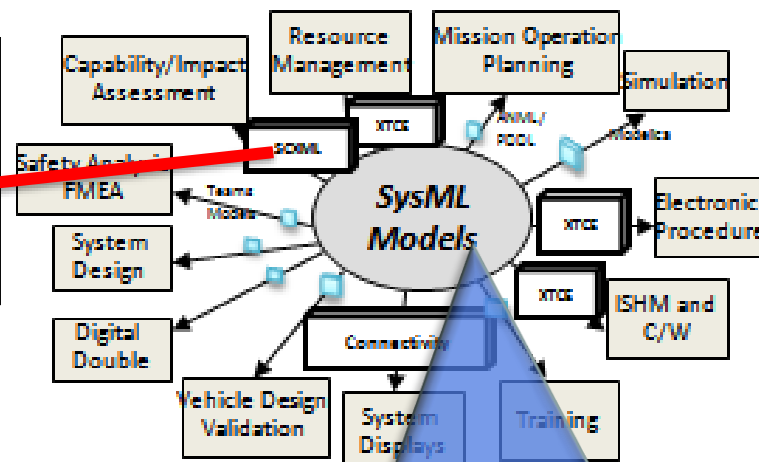


- ◆ The CDS is a water recovery system designed to support future human exploration missions beyond low earth orbit.
- ◆ The CDS system model was created using the same modeling method and tools.
 - Derived model artifacts in support of CDS system and software design
 - The project used the tools to extract master equipment list, connectivity, and XTCE information from the model.
- ◆ The design utilized the Fault Management (FM) methodology to incorporate FM elements into the architecture.
 - The behavior of each component was captured in state machine models using the methodology.
- ◆ The FMECA and Fault Tree tools were used to perform a risk analysis

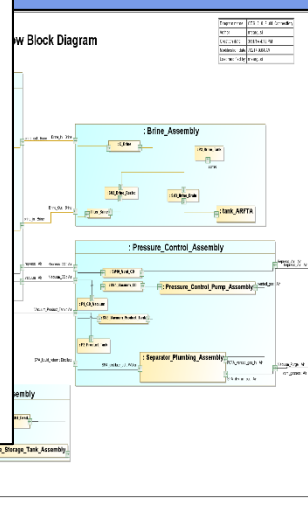
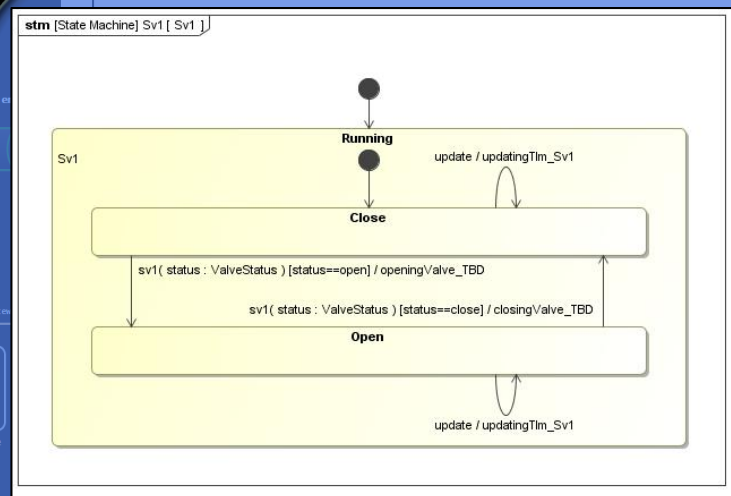
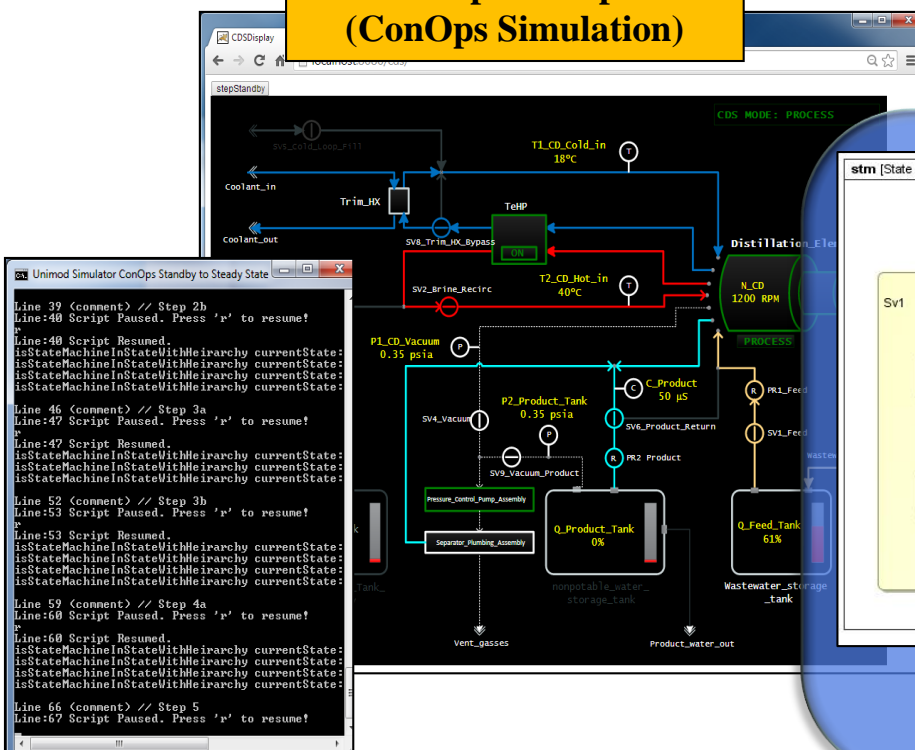




Extracted State Machine Data for ConOps and Risk Analysis



**Example Output
(ConOps Simulation)**



SysML Models

stm [State Machine] v02product [v02product]

Closed

{allocatedFrom = v02product
isolates CD from feed tank}

entry / feed delivery line closed

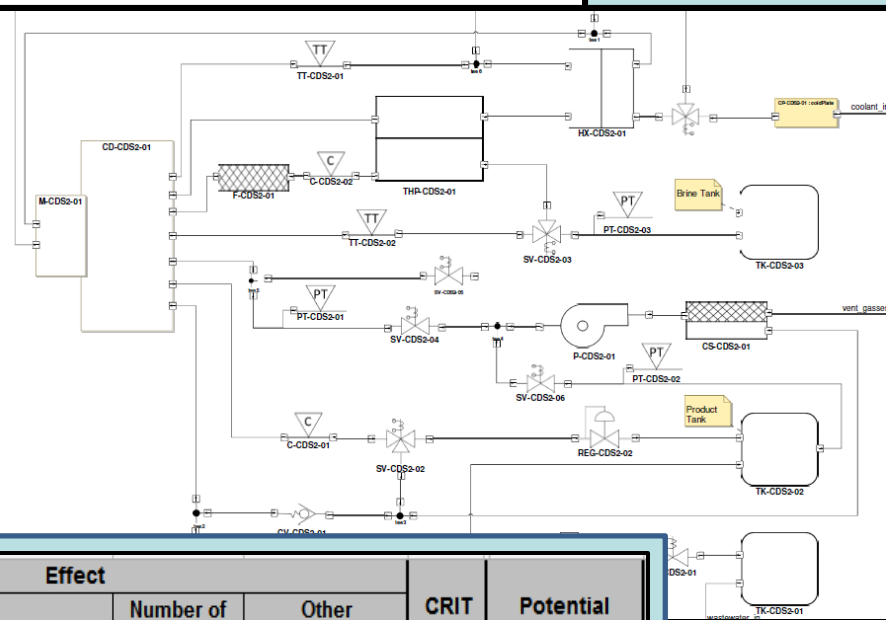
Int Struc

Int Structure_Failure()

«FailedState» failedClosed

{allocatedFrom = v02product
isolates CD from feed tank}

entry / feed delivery line closed

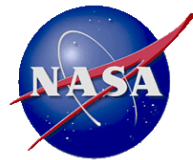


Generated FMECA Output

LRU/ Assembly Name	Item Name	Item Function	Potential Failure Mode	Effect				CRIT LEVEL	Potential Causes
				Immediate Failure Effect	End Effect	Number of Independent Failures	Other Independent Failures		
v02product	solenoid_valve_2way		failedClosed	v02product isolates CD from feed tank	CD does not generate distillate	1		3	Int Structure_Failure
v02product	solenoid_valve_2way		failedClosed	v02product isolates CD from feed tank	CD pumps fluids	1		3	Loss of Magnetic Field
v02product	solenoid_valve_2way		failedClosed	v02product isolates CD from feed tank	CD does not generate distillate	1		3	Loss of Magnetic Field
v04vacCD	nc_solenoid_valve		Failed Closed	v04vacCD isolates CD from vacuum	CD pumps fluids	1		3	Loss of Magnetic Field
v04vacCD	nc_solenoid_valve		Failed Closed	v04vacCD isolates CD from vacuum	CD does not generate distillate	1		3	Loss of Magnetic Field
v04vacCD	nc_solenoid_valve		Failed Closed	v04vacCD isolates CD from vacuum	CD pumps fluids	1		3	Int Structure_Failure
v04vacCD	nc_solenoid_valve		Failed Closed	v04vacCD isolates CD from vacuum	CD does not generate distillate	1		3	Int Structure_Failure
v04vacCD	nc_solenoid_valve		Failed Open	v04vacCD opens CD to vacuum		1		4	Int Structure_Failure
v04vacCD	nc_solenoid_valve		Failed Open	v04vacCD opens CD to		1		4	SpringFailure



FTA (Fault Tree Analysis) Extraction Tool



Magic Draw Plug-Ins



Select Top Level Event from Model to Analyze

Effect Block List

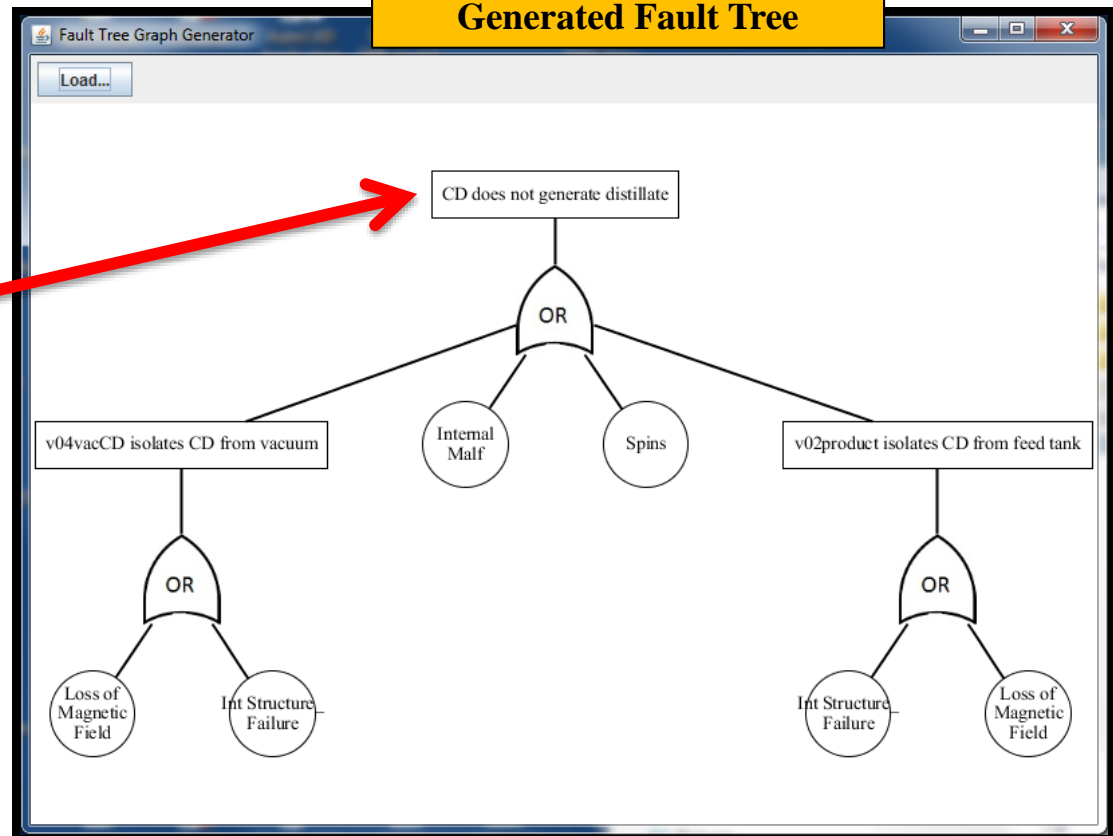
Select an Effect Block for analysis

- CD does not generate distillate
- CD does not pump fluids
- CD generates distillate
- CD pumps fluids
- no power from RPC_CDmotor
- no power from RPC_TeHP
- no power from RPC_vacPump
- no power from RPCv01
- no power from RPCv02
- no power from RPCv03

OK

Cancel

Generated Fault Tree





Conclusion and Forward Work



Conclusion:

- ◆ A combination of education and outreach, institutional support, and a set of modeling guidelines and tools, has been successfully applied to multiple projects at JSC
- ◆ These initial successes are showing the path to the generalized adoption of MBSE
- ◆ Benefits of MBSE adoption include:
 - Significant time and effort savings to generate the operational products
 - Providing a single source of knowledge with the latest system configuration
 - Improving communication between multiple disciplines such as software, hardware, systems engineers, and CAD model developers

Forward Work:

- ◆ Continue to enhance the import tools to import data into the model from local sources used by multiple stakeholders (Visio, Power Point, CAD)
- ◆ Explore the development of flexible tools by leveraging the latest technologies in Ontology development and reasoning engines to enable the tools to be independent of the selected modeling method